SINUS STIMULATION AS A FACTOR IN THE RESUSCITATION OF THE HEART.*

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The number of instances now on record of resuscitation of the apparently dead by means of massage of the heart[1] furnishes more than enough justification for the continued practice of this measure, the value of which was first indicated in 1874 by the experiments of Schiff on animals. At the same time the large number of failures to resuscitate by means of this method in cases to all appearances quite as favorable as those revived, demonstrates that there is still much to be accomplished in this direction. Even in the case of animals where every preparation for resuscitation has been made, the heart often cannot be made to beat by means of massage.

An analysis of the causes of cessation of the pumping action of the heart should be the first step toward the clarification of the difficulties in the way of resuscitation. The main possible causes of acute cardiac failure may be described as follows: (1) inhibition; (2) fibrillation of the ventricles; (3) loss of contractility due to (*a*) asphyxia, (*b*) anemia, (*c*) poisons, (*d*) acute dilatation, (*e*) long standing disease of musculature; (4) loss of rhythmicity: (*a*), (*b*), (*c*) as in (3), (*d*) disease of the *primum movens,* together with loss of rhythmicity of subjacent parts; (5) loss of conductivity together with loss of rhythmicity of subjacent parts. It should be stated that the causes mentioned under (3), (4), and (5) are nearly always associated in one and the same case, although it may be not in equal degree.

The possibility of, and the methods available for the resuscita-

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[1] For the literature see Metcalf, C. R., *Boston Med. and Surg. Jour.,* 1909, clxi, 9; and Jurasz, A. T., *München. med. Wchnschr.,* 1911, lviii, 83.

tion of the heart acutely insufficient as the result of one or more of the above mentioned causes may now be considered.[2]

1. Stoppage due to inhibition, such, for example, as occurs in the early stages of chloroform anesthesia, should be best combated by means of cardiac massage. This alone should suffice to maintain the circulation until the inhibition is removed. The administration of atropin might hasten the removal of the inhibition.

2. Fibrillating ventricles, it would seem, are beyond treatment. Garrey[3] has occasionally succeeded in stopping fibrillation of the dog's ventricle by means of stimulation of the vagus nerve. This measure, however, must be resorted to so soon after the inception of fibrillation that it can be of little assistance in the case of man, unless it should be shown that there is a decided difference in this regard between man and the dog. The statement of Arabian[4] to the effect that the high tension alternating current stops fibrillation would seem to require verification.

3, 4, and 5. Failure due to loss of contractility, rhythmicity, and conductivity, when due to general or acute conditions, should be benefited by massage. A majority of the cases of cessation met with clinically is occasioned by this combination. And the fact that a majority of the cases, many of them apparently favorable, cannot be recovered by massage alone, would seem to indicate the need of subsidiary measures. In so far as the heart is concerned, the action of any condition promoting insufficiency through the depression of any one or all of these properties of the heart muscle starts a vicious circle. If, for instance, the prime action be upon contractility, this through the insufficient propulsion of the blood resulting therefrom will in turn depress rhythmicity and conductivity. Even when contractility is supplied by the hand of the operator, rhythmicity or conductivity, or both, may fail to return.

In resuscitation experiments it can easily be shown that massage frequently restores irritability and contractility, but fails to develop spontaneous rhythmicity; the inner stimulus is lacking. In such cases it becomes necessary of course to supply the rhythm or to develop it. Since the contraction of the ventricles alone suffices to maintain an efficient circulation, restoration of the circulation might be accomplished by means of direct stimulation of the ventricles with rhythmical induction shocks.[5] That this procedure is, how-

[2] It is not the purpose of this discussion to describe in detail the methods of resuscitation as applied to the organism as a whole, but merely to recount the general principles for the resuscitation of the heart itself. Therefore no reference is made to the concomitant action of other factors, such, for example, as vasomotor failure.

[3] Garrey, W. E., *Am. Jour. Physiol.*, 1908, xxi, 283.

[4] Arabian, H., *Jahresb. ü. d. Fortschr. d. Physiol.*, 1903, xii, 57.

[5] Special forms of apparatus have been devised for the purpose of supplying such stimuli to the ventricles (Floresco, N., *Jour. de physiol. et de path. gén.*, 1905, vii, 785, 797).

ever, fraught with very great danger every one knows who has worked to any extent with the exposed heart. In the state in which we find them when attempts at resuscitation become necessary, the ventricles are extremely liable to fibrillate, and an induction shock, or a galvanic current of sufficient strength to elicit a contraction, will almost certainly set up fibrillation.[6] It is therefore not safe to supply the rhythm in this way.

The impulses supplied to the ventricles along the normal path,—the auriculo-ventricular bundle,—are not nearly so apt as is direct stimulation to cause the ventricles to fibrillate. In the case of a heart that has stopped beating, it does not, however, always suffice for the supplying of impulses along the usual path merely to start the auricles beating. Owing to lowered conductivity at the auriculo-ventricular junction, which is the part of the heart especially susceptible to unfavorable conditions, impulses originating in a beating auricle may fail to reach the ventricles. Nor is this the only reason for insufficiency of auricular impulses. Owing to the feebleness of impulses from a feebly beating auricle, or to reduced irritability of the ventricular muscle, the auricular impulses may fall below the threshold of the ventricles. In such an event any measure that would make the auricles spontaneously rhythmical, or would increase the strength of their impulses, might prove of very great assistance in the resuscitation of the heart. It is just here that the methods now employed for the resuscitation of the heart could be improved.

In some experiments described in 1910[7] it was found that strips of the auricles of the cat's heart when stimulated tetanically may become spontaneously rhythmical, and that by the same means the rate of an existing beat may be materially increased provided the part stimulated is the sinus region of the heart. Stimulation of other parts of the auricle,—for example, the vault, the right appendix, or the left auricle,—rarely if ever results in the development of

[6] We have had no opportunity to test in this connection the statement of Batelli (*Jahresb. ü. d. Fortschr. d. Physiol.*, 1900, ix, 69) to the effect that an alternating current of 120 volts causes fibrillation, whereas one of 240 volts and 45 cycles does not; indeed that it stops fibrillation and causes the heart to beat normally.

[7] Erlanger, J., *Am. Jour. Physiol.*, 1910–11, xxvii, 87.

a series of beats. Furthermore, it was found that short periods of tetanic stimulation of the sinus region materially increase the carrying power into the less rhythmical regions of the auricle of the impulses originating in the sinus, so that previously quiescent outlying regions may begin to respond to sinus impulses, or a feebly beating outlying region may begin to beat more strongly. It should be added that stimulation of the auricles proper is not without effect. It makes them more responsive to stimuli carried into them from without, the amplitude of the contractions so determined being materially increased thereby. These results raised the hope that attempts at resuscitation of the heart might be materially aided by combining with the procedures now more or less generally used tetanic stimulation of the auricles, particularly of the sinus region.

RESTORATION OF THE NORMAL RHYTHM IN THE PERFUSED HEART.

Observations on the artificially perfused heart have shown clearly the value of this procedure in cases where perfusion, a measure quite comparable in its effects to massage of the heart, fails to develop a normal heart beat. Two illustrative cases will be cited here. In both cases the heart (cat) had fibrillated and the fibrillations had been stopped by temporary perfusion with a 1 per cent. potassium chlorid solution. In one case (experiment 1, series I) upon reperfusion with Locke's solution the ventricles alone began to beat, at a very slow rate. Single induction shocks applied to the sinus region of the auricles with a pair of platinum electrodes caused the heart to respond regularly and in proper sequence to each stimulus, but upon the cessation of stimulation the heart beat resumed its previous state. Then the sinus region was stimulated tetanically. Immediately after the cessation of stimulation, and for some time thereafter the beat of the heart to all appearances was perfectly normal. Soon, however, the sequence underwent a gradual change until the ventricles contracted first, and the auricles almost immediately after them. By means of tetanic stimulation of the sinus the normal sequence was repeatedly restored.

In the other case (experiment 2, series I) after reperfusion with Locke's solution the ventricles alone began to beat. Tetanic stimulation of the sinus region once and for all started the normal se-

quence. Experiments of the same kind have shown that stimulation of other parts of the auricle than the sinus region will not restore the normal sequence of beat.

EXPERIMENTS ON THE EXPOSED HEART IN SITU.

Experiments were then made on the dog's heart, which was exposed in the manner usual for experimental purposes. The effect of the procedure upon the exposed heart was observed, and in addition the pressure in the carotid artery was recorded with a mercury manometer. The stimuli were applied to the sinus region through a pair of platinum electrodes, which in some cases were sewn to the heart, and in others were passed into the auricle through the jugular vein. The animals were completely anesthetized; the preliminary anesthesia in all cases was obtained with morphine and ether. The heart failure was brought on usually by allowing the animal to inhale chloroform through the tracheal cannula until the respirations ceased and by waiting, as a rule, until the heart stopped beating. In some experiments the animals were asphyxiated while under full ether anesthesia by clamping the trachea until the heart had stopped. Then artificial respiration was begun and steps toward resuscitation were taken. These consisted of tetanic stimulation of the sinus and direct massage of the heart applied sometimes at the same time and sometimes separately. Other accessory measures, such as abdominal pressure, the infusion of salt solution, with or without adrenalin, etc., were not employed. Massage of the heart would not have been employed had it not been found early in the course of the work that without it the heart started by stimulation would not develop a pressure that was sufficient to maintain the circulation.

Any one who has attempted to stop the heart by means of chloroform or asphyxia is aware of the fact that stoppage may result in several ways. It may be the result of inhibition, when it is sudden. More commonly it comes on gradually; the pulse becomes smaller and smaller, the blood pressure falls practically to zero, and soon, usually within a minute or two, the heart stops. Not infrequently, however, the heart continues to beat for many minutes, five, eight, or even more, after the pressure has fallen to its lowest level. The propelling power of the heart has practically ceased; the recording

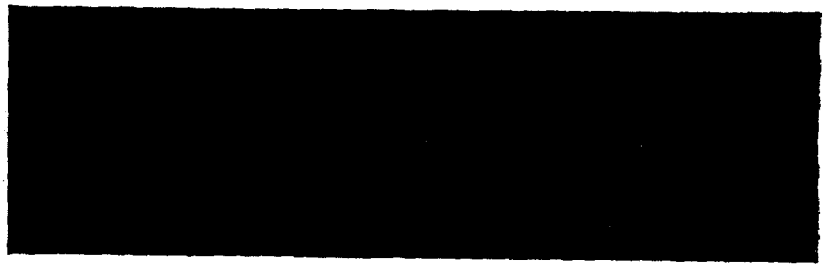
instrument may show only the faintest indication of a pulse. Occasionally the heart in this condition may recover under the influence of artificial respiration alone. On the other hand, it not infrequently happens that massage of the heart in addition to artificial respiration may fail to effect resuscitation. In such cases, as the protocols show, the beneficial effects of stimulation of the sinus region are especially striking.

In order to distinguish the beneficial effects of sinus stimulation from those of massage, the following procedure was usually followed. The heart was massaged as uniformly as possible several times, each time with the same number of strokes. In case this treatment revived the heart, the animal was again chloroformed or asphyxiated. In case it did not, approximately the same time interval was allowed to elapse between successive massages, and stimulation of the sinus region was combined with massage consisting of the same or of a smaller number of strokes.

It was discovered early in the course of the experiments that a wide range of strength of current could be employed for the purpose of making the auricles supply stimuli. A stimulus so strong as to cause the auricles to fibrillate has apparently been quite as effective as one not more than sufficient to start a regular beat. There was only this difference: the fibrillating auricle determines, as is the rule when conductivity is unimpaired, an irregular beat of the ventricles instead of a regular beat. In so far as the end results are concerned, however, the fibrillating and the regularly beating auricles are equally potent in that the arterial pressure maintained by the heart in delirium has been quite as high as that maintained by the heart at the moment it recovers from delirium (text-figure 1, *b*). For purposes of stimulation an inductorium was employed with five thousand windings in the secondary coil; it was actuated by one Edison-Lelande cell, type S. The distance between the secondary and the primary coils, as a rule, was between twenty and ten centimeters.

Not infrequently conductivity and irritability are lowered to such an extent by the cessation of the circulation that the impulses generated by an auricle that has been started by stimulation manifest no effect upon the ventricles. Under such circumstances mas-

sage and stimulation of the sinus have frequently caused the ventricles to beat with their inherent slow rate, although massage alone may have been without effect. I have no explanation to



1 2 3 4 5 6

TEXT-FIG. 1, *a*. Blood pressure in the carotid artery. Time in seconds. The signal indicates the level of zero pressure. (1) Massage. (2) Massage. (3) Massage plus stimulation; beat felt at point indicated by arrow. (4) Massage. (5) Massage plus stimulation; beat felt at point indicated by arrow. (6) Spontaneous ventricular contractions; the auricles are fibrillating.

offer of this beneficial effect of sinus stimulation upon the ventricles. The force of the ventricular beats so started has often been insufficient to maintain an effective circulation. As a rule, in such cases,

7 8

TEXT-FIG. 1, b. At 7 the impulses from the fibrillating auricles begin to affect the ventricles. At 8 the heart beat becomes normal.

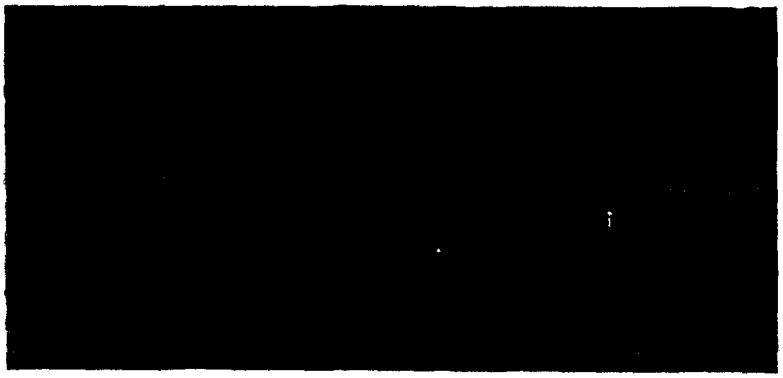
with the gradual improvement in the condition of the heart effected by the independent ventricles, the auricular impulses soon begin to reach the ventricles, with the result that the latter now beat more rapidly and effectively. In such cases, therefore, the beneficial

results of stimulation manifest themselves early, causing the ventricles to beat slowly, and also late, when the auricular impulses begin to effect the ventricles.

A large number of experiments have been performed; from these we select one typical experiment for the purpose of illustrating the foregoing discussion.

EXPERIMENT 4, SERIES II.

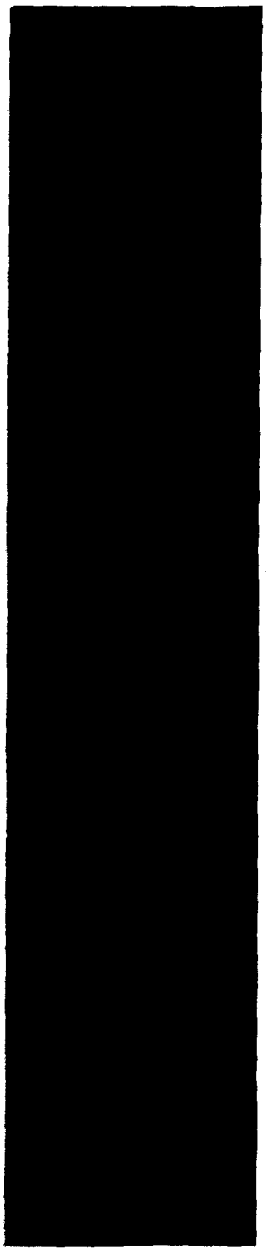
The stimulus was applied in this case to the inner wall of the right auricle, a stimulating sound having been inserted for this purpose through the jugular vein. Upon administration of chloroform, vagal effects appeared almost at once, and soon the respiration and the heart beat stopped. Massage given twice was negative (text-figure 2). Then stimulation was combined with massage. With



TEXT-FIG. 2.[8] Blood pressure in the carotid artery. Time in seconds. The signal indicates the level of zero pressure. (1) First period of massage. (2) Second period of massage. (3) Massage plus stimulation; beat felt at point indicated by arrow. (4) Massage plus stimulation; beat felt at point indicated by arrow. (5) Spontaneous ventricular contractions; the auricles are fibrillating.

the eighth compression of the heart a beat of the ventricles was perceived by the hand grasping the heart. After a pause, combined massage and stimulation were repeated. With the eighth compression another contraction of the ventricles was felt. Massage and stimulation were then stopped; the ventricles were seen to be beating slowly and regularly while the auricles seemed to be fibrillating. Suddenly the impulses of the fibrillating auricles began to affect the ventricles; at once the pressure, which had been practically stationary for some time, began to mount and soon reached its normal level. Later the fibrillations disappeared. Similar results were repeatedly obtained in this ex-

[8] All the text-figures have been reduced one half.



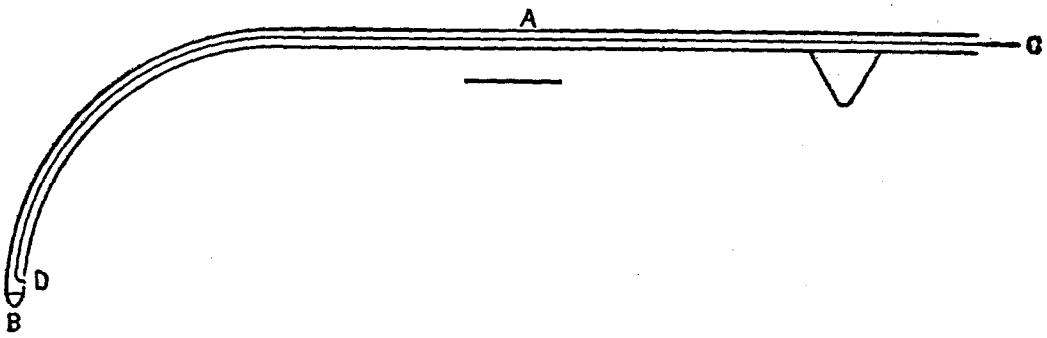
TEXT-FIG. 3. Blood pressure in the carotid artery. Time in seconds. The signal indicates the level of zero pressure. (1) The waves shown here are due to artificial respiration; the heart is not beating. (2) Massage. (3) Massage. (4) Massage plus stimulation followed by recovery of the heart.

periment (text-figure 1, *a* and *b*). Some of the trials show even more strikingly the beneficial effects of stimulation. For example, when the heart was stopped for the sixth time with chloroform the results were as follows: (*a*) massage (15 compressions), negative; (*b*) massage (10 compressions), negative; (*c*) massage combined with stimulation of the sinus; with the third compression a ventricular beat was felt under the hand; massage was immediately discontinued, but the heart did not beat further; (*d*) massage (10 compressions), negative; (*e*) massage plus stimulation; with the fifth compression the ventricles began to beat, while the auricles fibrillated. The ventricular beats were slow, strong, and regular until the impulses from the fibrillating auricles caused the ventricular beats to become irregular; thereupon results similar to those described above were again obtained. Later in this experiment (text-figure 3) the heart was recovered by massage plus stimulation but without fibrillation of the auricles.

EXPERIMENTS WITH THE CHEST UNOPENED.

After it had been demonstrated upon the heart freely exposed that stimulation of the sinus region is a valuable adjunct to massage in the resuscitation of the heart, the experiments were next directed toward devising a method of applying the principle in such a way as to make its use possible in the resuscitation of the heart of the ani-

mal with the chest unopened. Several procedures were considered: (1) The passage of currents through the heart either (*a*) by applying the electrodes externally, or (*b*) by applying one or both of the electrodes by way of the esophagus.[9] It was deemed inadvisable to employ either of these procedures, because of the difficulty of supplying currents of sufficient density at the desired place, and because of the risk consequently involved of exceeding the limit beyond which the ventricles might fall within the range of stimulation. (2) The use of a sound electrode applied to the sinus region through the jugular vein. The disadvantages of this method, which was also employed by Floresco for the application of a stimulus to the ventricles, are (*a*) the difficulty of bringing the electrode to bear against the sinus region of the auricles; (*b*) the time that is required to insert the sound into the vein; (*c*) the danger of passing the sound on into the ventricle; and (*d*) the danger of clotting. (3) The insertion of a sound electrode directly through the chest wall. A few trials convinced us that this method would be by far the



TEXT-FIG. 4. The stimulating sound electrode. A = steel tube; B = olive tip; C = insulated wire appearing at the surface through the insulated eye (D).

simplest and the least dangerous. A study of cross sections of the dog's chest indicated clearly the path that such a sound should be made to take, so as to reach the sinus region of the auricles.[10] The

[9] This approach has been used by Floresco (*loc. cit.*) for the stimulation of the whole heart.

[10] A fair idea as to the relations of the parts with which the sound comes into contact may be obtained from the cross sections of the dog's body published by Ellenberger and Baum, Anatomie des Hundes, Berlin, 1891. The plane in which the sound should lie is between those shown in plates VI and VII of their work.

sound finally developed is shown in text-figure 4 and requires no further description. It is inserted as follows: After nicking the skin in the third left interspace as close as possible to the sternal margin, the tip of the sound is placed against the subcutaneous tissue. It is directed perpendicularly to the chest wall and boldly pushed into the pleural space. The point is then directed to the right, and carried through the anterior mediastinum close to the sternum until it has passed some distance beyond the right border of the heart. The sound is then turned until the point looks downward and to the left, and while more and more of the sound is allowed to enter the chest, the outer end is carried upward and to the right. This pass will not meet with any resistance whatever, and will carry the point of the sound exactly to the sinus region of the heart. It just slides along the right side of the pericardium, or, in case it has been carried farther to the right, it is returned to the pericardium by slipping between the lobes of the lung from right to left. Unipolar stimulation is employed. The sound carries the stimulating electrode; the indifferent electrode is placed on the shaved thigh. The pericardium, it will be seen, lies between the electrode and the heart. Ordinarily it is so thin that it in no way interferes with the application of the stimulus to the heart. Occasionally, however, the pericardial fat is so abundant as to insulate the heart more or less completely. In such a case the method is of no value. In the course of our experiments this difficulty has been encountered only once. When the sound is withdrawn, even though no precautions are taken, air does not enter the chest, provided the subcutaneous tissue has not been cleaned away from the muscle. In practice, however, it might be well to take the precaution of laying a purse string ligature in the tissues about the sound, and of drawing it tight while withdrawing the sound. In this series of experiments stimulation of the sinus was employed as an adjuvant to subphrenic cardiac massage.

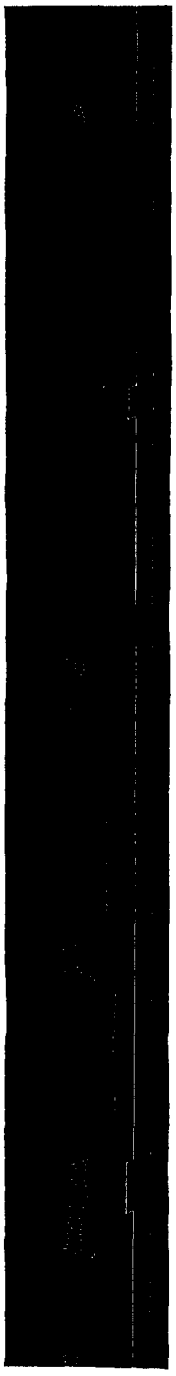
While the main object of this series of experiments has been to determine a feasible method of applying the tetanizing current to the sinus through the unopened chest, the experiments at the same time furnish additional indications of the value of the principle in the resuscitation of the heart. Brief extracts from the protocol of one experiment will suffice for purposes of illustration.

EXPERIMENT 12, SERIES III.

First Trial.—As a result of the administration of chloroform, respirations had ceased and the blood pressure had dropped to the lowest level. While the heart was still beating, artificial respiration was begun. Despite this the heart continued to grow weaker until its effect upon the record could scarcely be perceived. Ninety-three seconds after beginning artificial respiration, simple tetanic stimulation of the sinus did not improve the circulation. One hundred and sixty seconds later simple massage (20 strokes) effected only a very slight and transitory improvement. One hundred and five seconds after this, massage (20 strokes) combined with a short period of stimulation gave an immediate and perfect recovery.

Second Trial.—After the pressure had returned to normal, chloroform was again administered with results similar to those just mentioned. One hundred and seventy seconds after beginning artificial respiration, stimulation of the sinus region was negative. Ninety-five seconds later, massage (20 strokes) was negative. Text-figure 5 shows the terminal strokes of this period of massage. Thirty-two seconds later, massage (20 strokes) terminated by stimulation gave an immediate improvement. Two successive massages of 10 and 20 strokes each gave further slight improvement, while stimulation alone very materially hastened the recovery of the heart.

The third and fourth trials yielded results similar to those mentioned above.



TEXT-FIG. 5. Blood pressure in the carotid artery. Time in seconds. The signal indicates the level of zero pressure. (1) Termination of first period of massage. (2) Waves due to artificial respiration; the heart is beating, but the recording instrument shows no pulse. (3) Massage plus stimulation followed by improvement of the heart beat. (4) Massage followed by further slight improvement. (5) Massage followed by further slight improvement. (6) Stimulation followed by decided improvement.

RESUSCITATION OF THE ANIMAL.

In order to determine whether the method was suited not only to the temporary resuscitation of the heart and animal, but also to the permanent resuscitation of the apparently dead, in a few experiments the animals after resuscitation were permitted to recover

from the anesthesia. These experiments were performed under such aseptic precautions as it would be possible to employ in the case of an emergency. The animals were killed with chloroform administered in the usual way. Artificial respiration by the Meltzer and Auer method of tracheal insufflation was then started as quickly as possible. This often required several minutes. In some cases while this was being started an assistant made the incision into the abdomen through which subphrenic massage was to be given. In other experiments the abdomen was opened under ether anesthesia before the chloroform was administered. As soon as the artificial respiration had been started the stimulating sound was inserted. These preparations preliminary to beginning massage and stimulation usually required from four to six, or occasionally even ten minutes. Ten trials were made on as many animals. Three of these trials demonstrated clearly the value of stimulation as an accessory in permanent resuscitation. We do not mean by this to imply that stimulation was without effect in the other seven trials, but rather that in them the effects of stimulation were obscured by attending circumstances. Thus in some cases resuscitation was effected by artificial respiration or by artificial respiration and massage alone; that is to say, stimulation of the sinus proved to be unnecessary. In others accidents occurred which, it should be added, were almost invariably the result of inexperience rather than of any inherent defect in the method. In still others it happened that after successful resuscitation of the heart the respiratory center failed to become active. It is surprising how difficult it often is to stop the heart with chloroform. In the dog the respiratory center not infrequently recovers when the chloroform is withdrawn after respirations have ceased, and after the heart has become very weak. Indeed this may happen over and over again in the same animal, so that so much more chloroform has to be administered than is just necessary to stop the respirations that recovery of the tissues must become a much more difficult matter than in ordinary cases of chloroform poisoning. However this may be, it is obvious that the test to which the method is subjected in such experiments must be far more exacting than in usual cases of death from an overdose of chloroform on the operating table.

The protocols of two experiments will be given, one (experiment 9, series IV) for the purpose of illustrating the difficulties in the way of obtaining unambiguous results; the other (experiment 10, series IV), to illustrate a thoroughly successful resuscitation in which the value of stimulation of the sinus as an adjuvant to massage is clearly demonstrated.

EXPERIMENT 9, SERIES IV.

Time in minutes elapsing after beginning of chloroform administration.	Procedures and remarks.
0	Chloroform on.
½	Breathing stopped.
1½	Breathing begun.
1¾	Breathing stopped.
6	Heart very weak; artificial respiration.
6½	Massage.
7	Heart improved,[11] massage stopped.
9	Artificial respiration off.
9½	Spontaneous breathing.
10½	Chloroform on.
12	Breathing stopped.
13½	Heart slow and weak.
17	Artificial respiration on.
17¾	Heart beat scarcely palpable.
18	Heart stopped; massage.
18½	Heart beating; massage stopped.
19	Heart getting weaker.
19½	Massage.
20	Heart better; massage stopped.
22	Heart stronger; artificial respiration off.
24	No spontaneous respiration yet; heart weaker.
24	Artificial respiration on.
25	Heart very weak; massage.
26	Heart improving.
27	Massage off.
28	Artificial respiration off.
30	Spontaneous breathing.
31½	Heart weaker; breathing stopped.
32	Spontaneous breathing; heart improving.
36	Chloroform on.
38	Heart very weak.
38½	Heart stopped; massage.
40	Respiration stopped; artificial respiration and massage.

[11] The condition of the heart in this experiment was determined by palpation through the diaphragm either at the close of the periods of massage or during momentary interruptions of massage.

40½	Heart beating; artificial respiration and massage stopped.
41½	Heart weaker.
41¾	Artificial respiration on.
47	Heart very weak; massage.
47¾	Heart stopped.
48	Massage; heart beating shortly thereafter.
48½	Massage stopped.
49½	No improvement.
50	Heart weak.
50½	Massage plus stimulation.
51	Heart beating better; massage stopped.
53	Heart getting weaker.
53½	Massage.
54	Massage stopped; heart no better.
54½	Massage plus stimulation.
54¾	Heart better; massage continued.
56	No further improvement; massage continued.
57	Stimulation; massage continued.
58	Heart slow and no stronger; massage continued.
58½	Stimulation; massage continued.
59	Heart beating better; massage continued.
60	Beat slower; massage continued.
60½	Stimulation; massage continued.
62½	Heart beat fairly good; massage continued.
63½	Heart beat fairly good; massage continued.
67	Rectal temperature 31.5° C.
67	Artificial respiration off; massage stopped; heart continued to beat but the animal did not breath spontaneously; heart gradually weakened and stopped.

EXPERIMENT 10, SERIES IV.

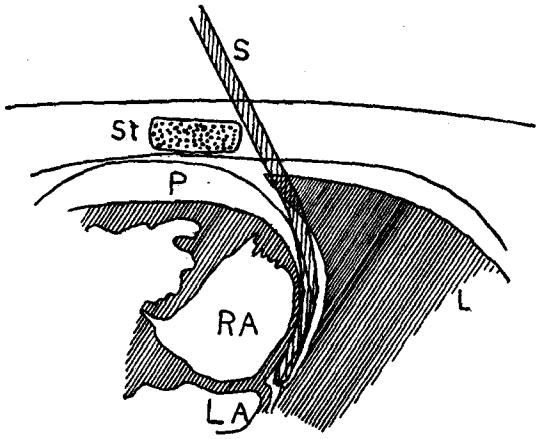
Time in minutes elapsing after beginning of chloroform administration.	Procedures and remarks.
0	Chloroform on.
1¼	Heart weaker.
2½	Breathing stopped.
3	Heart stopped.
3¾	Insufflation begun.
4	Massage.
4½	Heart not beating; massage continued.
5	Heart not beating; massage continued.
5¼	Heart not beating; massage continued.
6	Heart not beating; massage continued.
6½	Heart not beating; massage plus stimulation.
7	Heart not beating; massage continued.
7½	Heart not beating; massage plus stimulation.
9	Heart beating; massage continued.
10½	Heart beating; stimulation; massage continued.

11	Heart beating slowly but forcibly.
13½	Heart beat better but slow; massage stopped.
14	Artificial respiration off; spontaneous respiration begun at once. The wounds were closed aseptically, and the heart was beating strongly when the animal was taken from the table. Animal lived for seven days, and then died of intercurrent affection.

In this experiment insufflation was begun one and one fourth minutes after breathing had stopped, and massage of the heart one minute after the heart had stopped. Massage continued for two minutes failed to start the heart. The heart was first felt beating after the massage plus stimulation applied four and one half minutes after the heart had stopped.

APPLICABILITY OF THE METHOD TO THE RESUSCITATION OF MAN.

An examination of cross sections of the human body clearly indicates the feasibility of stimulation of the sinus region of the heart by the same method that has been employed in the case of the dog. Text-figure 6 shows the cross section of the body at the right level



TEXT-FIG. 6. Part of a cross section of the human body at the level of the second interspace. St = sternum; L = right lung; P = pericardial cavity; RA = right auricle; LA = left auricle; S = stimulating sound electrode.

for the introduction of the sound, with a sound of what would seem to be the proper shape in place. The opportunity has not been afforded to attempt the resuscitation of man by this method.

Accidents due to experimental manipulation have been very few. There is, of course, some danger of misdirecting the sound in such a way as to puncture the heart or lungs or to apply the stimulus to the ventricles instead of to the sinus region, thus causing the former to fibrillate. In our experiments the heart has never been punctured; the lungs were punctured once. The danger from this source is, therefore, very slight. And only once during the scores of times the current has been sent through the sound has fibrillation of the ventricles resulted. This danger cannot be great, since the sound when in the proper place can scarcely be brought into the vicinity of the ventricles; with practice in the passing of the sound one would soon learn to eliminate this danger entirely. A precaution that it might be well to take in order to obviate all danger of pneumothorax has already been referred to.

SUMMARY.

The four series of experiments described above indicate clearly that tetanic stimulation of the sinus region of the auricles is of material assistance to massage in the resuscitation of the heart. It causes the auricles to generate impulses, either rhythmical or irregular, to which the ventricles, when susceptible, respond. When massage administered for brief periods has failed to resuscitate the heart, the same period of massage combined with tetanic stimulation of the sinus has usually brought the circulation back to normal. In some instances massage alone when continued over long periods has been without effect, and to all appearances would have continued to be without effect, whereas at such a time massage combined with stimulation of the sinus has effected recovery. Whether the stimulus causes the auricles to beat normally or to fibrillate seems to make no essential difference in the end result. Not infrequently conductivity and irritability are lowered to such an extent by the cessation of the circulation, that impulses generated in an auricle started by stimulation can at first manifest no effect upon the ventricles. Under such circumstances massage alone or, more frequently, massage plus stimulation may cause the ventricles to beat with their inherent slow rate. Often then the force of the ventricular contractions is insufficient for the maintenance of an effec-

tive circulation. In such cases, however, with the gradual improvement in the condition of the heart, the auricular impulses, as a rule, soon begin to reach the ventricles, with the result that the latter immediately begin to beat more rapidly and effectively. The beneficial results of stimulation of the auricles, therefore, manifest themselves relatively late, but none the less effectively.

It has been found that even after the heart has begun to beat, stimulation of the sinus region may still be of some assistance, though in another direction. It not infrequently happens that after resuscitation of the heart the blood pressure fails to rise above a certain low and insufficient level. In such cases repeated tetanic stimulation of the sinus may accelerate the rise of blood pressure and so hasten recovery (protocol of experiment 12, series II, and text-figure 5). No attempt has been made to determine the mechanism of this effect.